TECHNICAL MEMORANDUM -

Updated (2007) Data Gaps Identification - Carson River Mercury Superfund Site

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DATE: July 31, 2007

Introduction

The U.S. Environmental Protection Agency (EPA), under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), is conducting a remedial investigation and feasibility study (RI/FS) to address mercury contamination in the Carson River system. The Carson River Mercury Superfund Site encompasses the entire Carson River system (CRS) below Carson City, Nevada, as well as the historic mill sites along the Carson River and tributaries in and around Dayton, Nevada. EPA has designated the CRS, including the Lahontan Reservoir and downstream wetlands areas into two Operable Units (OUs). An OU is defined in the National Contingency Plan (NCP) as a discrete action that comprises an incremental step toward comprehensively addressing site problems. The historic mill sites in the Dayton area comprise OU No. 1, and the CRS itself is OU No. 2. The OU2 designation was given specifically to address mercury contamination present throughout an extended stretch of the CRS.

Project History

The Carson River Mercury Superfund Site was established in 1990 in response to historical and scientific accounts of widespread mercury contamination dating from 1800s mining activities in the Carson River drainage. Subsequent investigations have been conducted to satisfy requirements of CERCLA as amended by SARA. The Carson River Site is separated into two OUs. This technical memorandum focuses mainly on OU No. 2, which is in the Remedial Investigation phase of the Remedial Investigation/Feasibility Study (RI/FS) process.

Background

A large number of studies and research projects have been conducted in the Carson River watershed that are directly related to the Carson River Mercury Superfund Site RI/FS. A brief, but not comprehensive, summary of findings from those studies is presented here. Key studies relating to research topics and potential remedial alternatives are addressed specifically below.

The pattern of mercury contamination within the river/reservoir system

A number of studies have documented the spatial extent and degree of mercury contamination within the Carson River watershed. The original mill sites appear to be less significant as mercury sources than the main river. Significant amounts of mercury have been carried into the river in the past and are now eroding from the channel banks and stream bed. Much of the mercury entering the Lahontan Reservoir becomes stored in the sediment, while the remainder is transported downstream to the Lahontan Valley wetlands. These patterns of deposition, erosion, and spatial distribution have been described by numerous studies (e.g., NDEQ 1985; Hallock et al. 1993; Bonzongo et al. 1996; Miller et al. 1994, 1995, 1998; Mach & Peterson 1999; Marvin-DiPasquale et al. 2001; Tuttle et al. 2001; USGS 2002).

Purpose

The purpose of this technical memorandum is to summarize past and present work at the Carson River Mercury Superfund Site that is relevant to the ongoing RI/FS process. Specifically, the primary objectives of this report are to:

- Summarize important data;
- Define critical data gaps,
- Suggest focused studies that will aid in remedial alternative formulation, screening, and evaluation,

Summary and Data Gaps

Data gaps may occur in a number of steps in the RI/FS process. OU No. 2 at the Carson River site is in the remedial investigation stage and the following discussion is related to data specifically needed to further and eventually complete the RI/FS process.

Nature and Extent of Contamination

Mill Sites

Historically, a large number of mill sites operated along the Carson River and its tributaries (e.g., Six Mile Canyon Creek and Gold Canyon Creek) where they processed ore and generated large quantities of mercury-contaminated tailings. As part of work on OU No. 1 at the Carson River Superfund Site, EPA characterized a number of the historic mill sites in and around Dayton and ultimately performed soil remediation activities at several of the historic sites. However, large quantities of mercury-contaminated tailings remain at historic mill sites along the Carson River and its primary tributaries from the estimated 7500 tons of mercury was lost during the milling process (Bailey and Phoenix 1944).

Based on studies of mercury loading in the river system over the last several years, the general consensus appears to be that ongoing loading of mercury contamination to the Carson River from the historic mill sites is relatively limited. This is based on the fact that peak river concentrations occur far downstream of the historic sites, the magnitude of total loading from the tributaries from the mill sites is fairly small because of the low surface water flow rates, and concentration spikes were not observed in the river downstream of historic mill sites.

USGS sampling, (summarized in Mach & Peterson, 1999) showed that a meaningful percentage of the total mercury (T-Hg) and methylmercury (Me-Hg) found in the Carson River enters the river in the Dayton vicinity (see results for the Carson River Below Dayton station in E&E, 1999). However, there is no way to delineate the portion of this mercury that may be coming from historic mill sites compared to that which is coming from erosion of contaminated stream bank deposits.

Six Mile Canyon Creek, Seven Mile Canyon Creek, and Gold Canyon Creek were evaluated with high resolution remote sensing in 1990-1991 to produce maps showing the extent of mercury containing tailings along these tributaries (Fenstermaker 1992). Gold Canyon showed the largest areas of contamination.

- Existing mill site data should be summarized, including a qualitative assessment of the potential for the sites to contribute contaminated tailings/soil or sediment to the CRS.
- The locations of historic mill sites and potential continuing sources of contamination (tailings distribution) to the river should be included as a layer in a GIS database describing the CRS.

Channel Banks and Historic Channels

Historic releases of contaminated mill tailings and sediment from the milling operations along the Carson River and its tributaries have resulted in extensive deposits of mercury-contaminated sediment along the Carson River. Contaminated sediments are found in both the banks of the current channel and the abandoned meanders of the historic channel, between Carson City and Lahontan Reservoir. The most extensive collection and evaluation of bank sediment concentrations along this stretch of the river is described in considerable detail in Miller et al. 1998. As part this effort, samples were collected from channel banks and within the river channel at 18 locations above Lahontan Reservoir. Marvin-DiPasquale et al. (2001) collected multiple samples from actively eroding bank sediment at one location in 1999.

Erosion of contaminated sediment from channel banks is currently the leading source of mercury to the river system. Miller et al. (1998) depict a very complex alluvial sequence in the channel banks and along the river. The complexity of this sequence results in significant spatial variation in mercury concentrations along the river. Mercury fate and transport patterns in surface water are further associated with flow patterns on the Carson River and in Lahontan Dam from Marvin-DiPasquale (2003), summarized in Byron et al. (2004). These data could be used to validate current models or synthesized into revised mercury loading models for the Carson River (Warwick and Heim 1995).

Because the contaminated sediments in the channel banks and historic channels represent the primary source of current and potential future mercury loading to the river system, a thorough understanding of the distribution of contamination in these sediments is crucial for the RI/FS effort. However, the linear extent of channel and overall size of the area requiring characterization makes this difficult.

To complete the necessary characterization in a cost-effective manner, a sequential, focused data collection effort is recommended:

- The initial activity should consist of a "paper review" to identify and map potential "hot spots" of contamination along the river channel between Carson City and Lahontan Reservoir. This should include compilation of past sediment sampling results and review (and expansion or updating, if necessary) of the aerial photo evaluations performed by Miller et al. (1998) to help identify potential areas of concern based on changes in river channel location over time or visual evidence of extensive channel bank erosion. A visual comparison (overlay) of the historic channel location during mining and the current channel location could potentially show areas where previously deposited mercury tailing are being liberated into the Carson River. Previous investigators could be contacted to review and compile any mapping/characterization of the river banks that has already been completed as part of past sampling.
- All available maps and analytical results should be digitized into a GIS database after this initial "paper review". Geospatial analysis tools will support remediation action evaluation and planning.
- Geospectral mercury mapping in the tributaries not previously assessed by Fenstermaker (1992) and in the main channels during dry periods may reduce much of the uncertainty associated with this source evaluation and identify areas for more focused assessment and potential "hot spots" or areas of concern. This method will first have to be validated with field confirmation sampling to determine how accurately mill tailings predict mercury concentrations and for the appropriateness of this method for identifing mercury-containing tailings in exposed banks.
- Once the historical site mapping and remote sensing maps have been completed, it is likely that confirmation field sampling of bank sediments will be required to validate the geospatial mapping, fill data gaps, and to confirm potential "hot spots" or areas of concern.
- A GIS database should be built with layers describing current and historic channels in the CRS. Mercury concentrations in sediments and banks can also be added to this GIS database for identifying potential remedial action sites.
- The final step would be the sampling and characterization of bank sediments focused in areas selected for potential remedial actions. Additional samples should also be collected from soil in areas likely to be exposed by future erosion. These samples would help in predictive models for future mercury loading.

The results of this more detailed characterization would be combined with the results of the literature review and geospectral maps to provide a complete understanding of the distribution and volume of mercury-contaminated bank sediments contributing to the mercury load in the Carson River.

Once this characterization of source areas is complete, it may be appropriate to select one or more locations where pilot-scale erosion control projects can be performed on the eroding bank sediments. Areas that are contaminated and subject to significant erosion would be monitored for a period of time to establish baseline erosion and mercury loading rates.

River Channel Sediment

As is the case for the river bank sediments, an extensive collection and evaluation of river channel sediment concentrations is described in considerable detail (Miller et al. 1998; Marvin-DiPasquale et al. 2001). Sampling results from within the river channel at 18 locations above Lahontan Reservoir indicate that the T-Hg concentrations in river channel sediments are consistently one to two orders of magnitude lower than those found in the river banks (Miller et al. 1998). These results indicate that contaminated sediments are not accumulating in the bottom of the river itself. Further mercury speciation sampling was conducted in 1998 and 1999 from the Carson River, Lahontan Reservoir, and the Lahontan Valley Wetlands as part of mercury bio-transformation studies (Marvin-DiPasquale et al. 2001). Me-Hg concentrations are typically highest in the Fort Churchill and Delta areas and the highest concentrations occurred during the summer and fall. This time of year is characterized by low flow rates and high temperatures in this stretch of the river. Seasonal sediment variability in Me-Hg formation and degradation as related to flow regime were also significant. Therefore, areas of high Me-Hg formation that may be targeted for remedial action should consider these seasonal patterns.

Based on these findings, no further characterization of the river channel sediments is recommended. However, as part of the data gathering and compilation process described above for the river bank sediments, available sampling results for the river channel should be compiled and mapped. Additional sediment characterization may be necessary if remedial alternatives targeting these sinks and Me-Hg production areas are considered for further investigation. Earlier sampling, although comprehensive, may not describe the current spatial distribution of bedload Hg and Me-Hg. It is logical to assume that the river load mercury contamination will continue to move downstream, gradually and intermittently, over time.

Carson River Water

Mercury conveyance from source areas to the river sediments and reservoir are controlled by surface water movements. Patterns of surface water deposition, erosion, and spatial distribution have been described by numerous studies (e.g., Bonzongo et al. 1996; Mach & Peterson 1999; Marvin-DiPasquale 2003) and are summarized in Byron et al. (2004). In general, T-Hg and Me-Hg behave as particulate load and are strongly associated with flow and TSS in the Carson River upstream of Lahontan Reservoir. However, flow associated transport in Carson River is more closely associated with episodic increases in discharge than with long-term high flows. This is because actively increasing flows liberate T-Hg from bank sediment, but maintained high flows do not continue to liberate as much T-Hg and dilute the load (Byron et al. 2004). These conclusions were based on data from one station (Weeks Bridge) above Lahontan Reservoir collected from 1997 to 2004.

Measuring seasonal variability in flows, TSS, dissolved mercury, T-Hg, and Me-Hg have been invaluable for understanding fate and transport in the CRS and should be continued. Mercury load (T-Hg and Me-Hg) monitoring in Carson River should continue in at least four of the locations monitored by USGS (Marvin-DiPasquale 2003): Below Dayton, Fort Churchill, Delta, and Below Lahontan Reservoir to further characterize seasonal and year-to-year variability. Further evaluation will better characterize the sources of the T-Hg and Me-Hg transported downstream in the river system, particularly in the downstream stretch of the upper river (i.e., the stretch from below Dayton to the delta above Lahontan Reservoir).

- Continued tracking of Me-Hg and estimating the relative importance of sources that contribute to bioavailability is important in determining a baseline condition and evaluating changes over time after remedial options are implemented.

Lahontan Reservoir

Water and Sediment

The storage, recycling, transformation, and release of mercury in Lahontan Reservoir are key components in our understanding of the dynamics of mercury and mercury exposure in the CRS. It is the major storage site for eroded and transported mercury from the mill sites and acts to control the availability of mercury exposure to biota within the reservoir as well as for the downstream wetlands and wildlife management areas. The Lahontan Dam prevents the migration of bottom sediment and stores up to 90 percent of the mercury entering from the Carson River (Hoffman and Taylor 1998). Over half of this retained mercury settles in the delta and deep channel, with the mass of mercury contained in reservoir sediments estimated at over 300,000 kg (Miller et al. 1995).

A thorough mathematical model was developed to estimate mercury speciation, transport, and biotic transport in Lahontan Reservoir (Ghandi et al. 2007). This new model expands upon the previous understanding of reservoir sedimentation and mercury speciation, transformations, storage and loss processes (e.g. E&E 1998; Miller et al. 1995) that was based on limited data. The initial in-reservoir model presented in the ecological risk assessment (ERA) considered high-flow periods and did not show the effects of seasonal stratification and surficial sediment anaerobiosis on mercury bioavailability and mobility (E&E 1998). The newer model is based on seasonal inputs from Carson River, overlying water, and deeper water sediment cores described by USGS (2002). The new model predicts that the water column acts as a sink for Me-Hg primarily through uptake to biota (i.e., fish) and demethylation. Sediment Me-Hg production is high, but the flux of Me-Hg to the water column is limited by geochemical factors (Ghandi et al. 2007).

Lahontan Reservoir sediment data suggest there is a large spatial variability in net sediment mercury (Miller et al. 1995). Methylation is dependent on oxygen availability, organic content, and sulfide concentrations (Ghandi at al. 2007; USGS 2002; Marvin-DiPasquale and Oremland 1999). Other studies have documented variability in sediment mercury methylation and concentrations throughout the river/reservoir system, but were based on too few samples to describe spatial variability in any detail (e.g. Marvin-DiPasquale et al. 2001; Chen et al. 1996; Bonzongo et al. 1996).

There is good conceptual understanding of sediment characteristics, stratigraphy, transport, and ranges of T-Hg and Me-Hg concentrations in Lahontan Reservoir (Miller et al. 1995, 1998). A fate and transport model describing mercury speciation and methylation ties these concepts and data into a quantitative tool (Ghandi et al. 2007). These data are also important in determining the location and extent of mercury exposure to humans and wildlife and will benefit an updated risk assessment by reducing uncertainty for these parameters.

- Assuming remedial actions would not include reservoir sediment actions, an updated sediment characterization would not be necessary to characterize the current conditions of sediment concentrations throughout the reservoir.
- Compilation of future data will support the understanding of how these processes vary over time, validate the mathematical fate and exposure model, complement the general sediment characterization, and expand the ability to identify areas for potential remediation projects.

Lahontan Reservoir Biota

Lahontan Reservoir has been the site of numerous biological investigations, many of which were summarized in the Ecological Risk Assessment (E&E 1998). Birds, fish, and invertebrate dietary items have been well characterized for tissue mercury concentrations and exposure-related effects (E&E 1998). A recent sampling program targeted sport fish in Lahontan Reservoir, as well as Sacramento blackfish, which are harvested and shipped as live fish for markets in the Bay Area (NDOW 2006). Tissue metal concentrations from these samples are suitable for determining human and ecological risk. Fish consumption advisories have been issued for people eating Lahontan Reservoir fish (ATSDR 2003)

- Mercury concentrations in fish and wildlife tissue should continue to be monitored and linked to inter-annual hydrologic regimes to further human and avian risk assessments.

Lahontan Valley Wetlands

Water and Sediment

Transport to the Lahontan Valley wetlands downstream of Lahontan Reservoir continues to occur mostly via particulate Hg in the reservoir discharge (Tuttle et al. 2001). These particulate loads from the reservoir are dominated by bioaccumulated Me-Hg (plankton, seston), unlike the inorganic particle associations and amalgams dominating mercury transport upstream of the reservoir. However, similar to the upper Carson River, mercury loads in the lower Carson River may increase substantially following flood events when elevated mercury in historical channel sediments are scoured.

USGS, USFWS, and USEPA have documented T-Hg and Me-Hg loading downstream of Lahontan Reservoir in recent years (Tuttle et al. 2001; E&E 1999). The most current USEPA and USFWS joint effort collected water, sediment, and aquatic insect (Family: corixidae) samples from numerous wetlands in the Stillwater and Fallon National Wildlife Refuges for T-Hg and Me-Hg characterization in 1999 (Tuttle et al. 2001). The highest sediment T-Hg concentrations were found in wetlands that had formed pre-dating construction of the Lahontan dam, so that Carson River mercury was transported to them without settling losses and transformations inherent in the reservoir. Concentrations declined with wetland distance further downstream of the river source. A T-Hg concentration gradient was also found in constructed wetlands, built in the 1940s, and all wetland sediments had T-Hg concentrations greater than background. Me-Hg concentrations in sediment correlated with T-Hg, but the percent Me-Hg declined at higher T-Hg concentrations. Most surface water Me-Hg and T-Hg was associated with particulates, and HgT corresponded with turbidity and underlying sediment concentrations.

An extensive series of samples of surface water and groundwater, sediment, and biota were analyzed for a number of elements (including mercury) as part of the Irrigation Drainage study of the Stillwater Wildlife Management area (Hoffman et al. 1990, Hoffman 1994). Early investigations of T-Hg contamination in detrital matter from agricultural drains and wetlands in the Lahontan Valley by Hallock et al. (1993) are summarized in Tuttle et al. (2001). These studies found the highest Hg concentrations in the Lahontan Valley were associated with historical Carson River channels prior to water controls after construction of the reservoir. Historical chemical characterizations by the USFWS Irrigation Drainage Program investigations (Hoffman 1994) did not emphasize mercury; neither did these historical investigations identify areas of mercury storage, transformations, or methylation.

- Additional sediment samples should be analyzed for Me-Hg and T-Hg in the wetlands to identify potential "hot spots".
- The limited sampling conducted in agricultural drains suggests that these may be important mercury sources to the wetlands. The extent of T-Hg and Me-Hg and factors contributing to Me-Hg production in these drains will permit an evaluation of Me-Hg production there.
- Available data should be integrated into a GIS database where it can be used for risk assessment updates, evaluating remediation options, planning remedial actions, and monitoring changes or mercury attenuation after remediation.

Lahontan Valley Biota

The Lahontan Valley wetlands biota were sampled as part of the USFWS and USEPA investigations (Tuttle et al. 2001) as well as the Irrigation Drainage Program sampling (Hoffman 1994). Investigations completed since the 1998 ERA have focused on further characterizations of avian exposure and risk in the reservoir and downstream wetland areas (USGS 2002) as well as in dietary items for fish and shorebirds in the downstream wetlands (Tuttle et al. 2002). Aquatic insect tissue residues (Family: corixidae) were predominantly Me-Hg and showed a significant correlation with sediment Me-Hg (Tuttle et al. 2001). Biota-sediment accumulation factors (BSAFs) for Me-Hg from sediment to tissue ranged from 100 to 2000. Spatial variability was also observed with higher BSAFs and tissue concentrations occurring in constructed wetlands. Regression based uptake factors for wetland types were also developed and had different slopes. As with sediment, there was a weak negative correlation between Me-Hg in corixids and water column pH. Therefore, alkaline conditions may be somewhat protective against MeHg uptake to invertebrates in Lahontan Valley wetlands.

The effects of mercury contamination on avian wildlife in the Lahontan Valley have also been thoroughly studied (e.g., Henny et al. 2002; Henny et al. 2007; USGS 1999a). Adult fish-eating birds (double-crested cormorants [*Phalacrocorax auritus*], snowy egrets [*Egretta thula*] and black-crowned night-herons [*Nycticorax nycticorax*]) nesting along the lower Carson River contained very high concentrations of T-Hg and Me-Hg in livers and kidneys (Henny et al. 2002). The adults were able to tolerate these high concentrations by demethylating mercury when concentrations reached a threshold. A short exposure prior to egg laying and the internal sequestration reduced Me-Hg in eggs below effect levels for decreased hatchability. Young birds accumulated Me-Hg from their diets through fledging. During this period, mercury contributed to immune (spleen, thymus, bursa), detoxicating (liver, kidneys) nervous system, toxicity, as well as metabolic stresses (Henny et al. 2002).

Water concentrations of Me-Hg also correlated with concentrations in heron blood, egret blood, and heron eggs (Henny et al. 2007).

- The data for free-swimming hemipteran insects (corixids) did not include some of the more common dietary items as well as those invertebrates most likely to bioaccumulate mercury directly from the sediment (i.e., midge larvae) or those more likely to appear as dietary items (e.g., large beetles were very common dietary components in the most recent USGS results and fish were not sampled in the wetlands in the latest USGS effort). Additional dietary items for wildlife should be sampled for T-Hg and Me-Hg to improve risk characterizations.
- Studies have shown both temporal and spatial variability in biota samples and BSAFs. Additional samples may be needed to clarify the causal mechanisms for these changes and to assist with the design of possible remedial alternatives.
- A wildlife risk assessment should be updated with currently available data.

Mercury Speciation and Methylation

Knowledge of mercury speciation and transformation is important to a thorough understanding of human and ecological risk in the system. Mercury bioavailability is directly related to the concentration of methylated mercury in the system. Microbial mercury transformation studies the Carson River, Lahontan Reservoir, Carson sink, agricultural drains, and the Lahontan Valley Wetlands identified areas of significant Me-Hg formation (Marvin-DiPasquale et al. 2001). The comprehensive methylation study by Marvin-DiPasquale et al. (2001) found that conditions for methylation were more favorable in the river and agricultural drains than in the reservoir or wetlands. Net methylation was highest at and downstream of Fort Churchill, a mainstem river area of organic-rich sediment accumulation conducive to Hg-methylating anaerobic sulfate reducing bacteria. The next highest net methylation rates were found in agricultural ditches and lakes of the lower marsh area, below Lahontan Dam. In contrast, rates were lower in the mainstem river stations where organic compounds were less abundant. Mercury demethylation was greatest in the agriculture drains and wetlands. These trends are explained by site-specific geochemical characteristics and resulted in a general decrease in net methylation from upstream to downstream. Previous investigations found possibly opposite trends, where mercury methylation rates (or at least, concentrations) generally increased moving downstream from the mill sites and into the lower, organic-rich sediments of the lower river/reservoir system (Bonzongo et al. 1996; Chen et al. 1996).

Carson River is the most important source of Me-Hg to the reservoir despite significant mercury methylation occurring in reservoir sediment (Ghandi et al. 2007). The reservoir sediments are a major source of Me-Hg maintaining elevated water concentrations, although Me-Hg diffusion from the reservoir sediment to the water column is limited by geochemical processes.

Downstream effects on methylation have been noted as well. Enhanced methylation was expected in the marshes downstream of Lahontan Reservoir; however the formation of reduced sulfur compounds appears to inhibit mercury methylation in many of these organic-rich areas. Nevertheless, the large spatial area of the marshes suggest their importance in creating mercury exposure to biota (Marvin-DiPasquale et al. 2001).

- Methylation/demethylation measurements and other studies indicate that the river/reservoir system is complex and that a thorough understanding of the patterns of mercury methylation and biotic exposure may require further study. The reasons for uncertainties in conclusions concerning net production of Me-Hg should be investigated and clarified.
- The potential for Me-Hg production in wetland root zones has not been evaluated. It is recommended that this potentially active Me-Hg production area should be sampled and compared to a reference area to evaluate the significance of this process and potential implications of water management and remedial design decisions (Marvin-DiPasquale et al. 2001).

Ecological and Human Health Impacts

The initial summary and analysis of ecological impacts provided a good summary of impacts to the resident piscivorous birds of Lahontan Reservoir and of body-burdens in fish (human health impacts), birds, and invertebrates (E&E 1998). Further studies have helped to reveal several impacts to various bird species, both at the Reservoir and downstream in the wetland areas (Henny et al., 2002; Henny et al. 2002; USGS 1999a). Human health risks from fish consumption have been evaluated in the Lahontan Reservoir where there are elevated mercury concentrations in game fish fillets (ATSDR 2003). These focused sampling and bioaccumulation studies conducted since the initial risk assessment will reduce uncertainties in updated human health and ecological risk assessments.

Ecological and Human Health Risk Assessment

The 1998 ERA (E&E 1998) was based on data collected through 1994. This original risk assessment confirmed the relatively high levels of mercury in water and sediment and the biomagnification in fish, birds, and their dietary items. The summary of reservoir loading, fate, and transport of mercury in the 1998 ERA also assumed only totally mixed reservoir conditions under high, spring inflows, with no reservoir stratification or associated seasonal oxygen depletion (E&E 1998).

Piscivorous birds in Lahontan Reservoir were suggested to be at the greatest toxicological risk (E&E 1998). Initial post-ERA results were equivocal. Reproductive impairment and other toxic effects were not apparent in fish eating birds downstream of Lahontan Reservoir despite elevated tissue burdens in birds and their eggs (E&E 1998, Henny et al. 1998). Follow-up studies in the lower Carson River identified compensatory mechanisms that are somewhat protective of adult fish eating birds (Henny et al. 2002). However, mercury contributed to immunotoxicity and other molecular indicators of stress in young birds with high mercury containing diets. These findings support data from Tuttle et al. (2001) who concluded that HgT and Me-Hg in water and sediment, and corixids presented a risk to fish and wildlife in wetlands downstream of Lahontan Reservoir. HgT concentrations in biota varied over time and risks to migratory birds and other wildlife may also vary over time. Higher invertebrate BSAFs in constructed wetlands also drove greater potential risk to insectivorous fish and birds (Tuttle et al. 2001).

- Recent studies have filled many data gaps that existed at the time of the initial ERA and indicate the need for updating. The comprehensive ERA for the Carson River site should be re-evaluated with these new data, including site-specific parameters (i.e., regression based uptake factors) that account for spatial differences between constructed and natural wetlands.

Human health risks are also presented by mercury in animal tissues consumed as food from Lahontan Reservoir. Fish (channel catfish, white catfish, white bass, large mouth bass, and walleye) and two species of duck (shoveler and green-winged teal) tissues contained greater than the 2.6 ppm mercury that would result in an exposure exceeding the MRL for an adults (ATSDR 2003).

Recommendations and Conclusions

This summary of past and present mercury investigations at the Carson River Mercury Superfund Site identified data gaps that are relevant to the ongoing RI/FS. Select data on mercury fate and transport, methylation, water and sediment characterization, and ecological effects assessments is presented here and additional studies are suggested to fill data gaps. Significant work has been done since the previous data gaps analysis in 1999 and much of the suggested actions involve data compilation and evaluation.

The ability to proceed with the RI/FS process will require filling data gaps through specific actions:

1) Existing mill site data should be summarized, including a qualitative assessment of the potential for the sites to contribute contaminated tailings/soil or sediment to the CRS. A map should be included that presents the locations of any historic mill sites considered to be potential continuing sources of contamination to the river.

2) A GIS database should be built to describe all known aspects of the CRS. This would be an invaluable tool for future risk assessment updates, evaluating remediation options, planning remedial actions, and monitoring changes or mercury attenuation after remediation. Data (layers) would include:

    - Historic mine and mill sites;
    - Surface deposits of mercury containing tailings from remote sensing investigations;
    - Current and historic channel locations of the Carson River upstream of Lahontan Reservoir;
    - Sediment and water concentrations; and,
    - Biota concentrations.

3) Carson River channel bank hot spots should be identified and mapped through screening-level sampling and more detailed, focused sampling following a review of existing sampling results, aerial photos, and mapping of sediment deposits. Following the characterization of bank sediments, an erosion control pilot study could be performed where erosion rates and mercury loading data would be collected before and after installing erosion controls on a defined section of eroding stream bank.

4) Mercury loading (T-Hg and Me-Hg) should continue to be monitored at selected locations along the CRS to track seasonal and annual variability, as well as changes

following remedial actions. Recommended monitoring locations include four of the locations monitored as part of the recent USGS monitoring activities along the river: Below Dayton, Fort Churchill, Delta, and Below Lahontan Reservoir. The monitoring frequency should vary throughout the year, averaging approximately 10 sampling events per year.

5) The spatial pattern of mercury contamination in wetlands downstream of Lahontan Reservoir, including methylation and transport in the agricultural drains, should be evaluated and mapped. This additional information about a potentially important Me-Hg source will support the evaluation of potential water management strategies.

6) Focused invertebrate and sediment sampling may be necessary as a means of detailed exposure mapping in areas of the wetlands that are candidates for remedial actions.

7) Small fish tissue concentrations are needed from the lower Carson River wetlands. These data will be used to estimate exposure concentrations for piscivorous wildlife.

8) A comprehensive ERA, incorporating the results of all ongoing and new studies, should be prepared for the entire Carson River, Lahontan Reservoir, and downstream wetlands systems. The system should be evaluated as an integrated whole to gauge ecological risk more effectively. Wildlife hazard assessment conclusions can be compared to existing wildlife effects study results for validation.

9) The biotic community of the reservoir and wetlands should be evaluated for evidence of impairment relative to comparable environments with reduced mercury contamination. The revised ERA is currently faced with evaluating the effects of multiple stressors including elevated mercury, other trace elements, TDS, sediment, and water level fluctuations. In addition, the long-term mercury exposure in the area may have produced mercury-resistant communities. A more thorough evaluation of the community structure and quantification of the various stressors will be important when re-evaluating new data in an updated risk assessment.

10) The fishery in the reservoir has been evaluated with the intent of imposing fisheries management. Fish should continue to be sampled annually for assessment of potential mercury exposure to birds and humans.

11) A remedial option evaluation should be performed following the ERA update. Areas of greatest potential risks and greatest potential for improvement can be identified in the ERA to focus the remedial option evaluation.

References

Agency for Toxic Substances and Disease Registry (ATSDR). 2003. Analysis of the Human Exposure Pathway via Surface Water, Sediment, and Biota in Churchill County. Fallon Leukemia Project, Churchill County, NV, December.

Bailey, E.H. and D.A. Phoenix. 1944. Quicksilver Deposits in Nevada. University of Nevada Bulletin. 38:12-46.

Bonzongo, J.C., K.J. Heim et al. 1996. Mercury levels in surface waters of the Carson River-Lahontan Reservoir system, Nevada: Influence of Historic Mining Activities. Environ. Pollut. 92(2): 193-201.

Bonzongo, J.J., K.J. Heim, Y. Chen, W.B. Lyons, J.J. Warwick, G.C. Miller, and P.J. Lechler. 1996. Mercury pathways in the Carson River-Lahontan Reservoir system, Nevada, USA, *Environmental Toxicology and Chemistry* 15:677-683.

Byron, E., A. Tsao, and D. Towell. 2004. Evaluation of Carson River Water Quality Data: 1997 – 2004. Technical Memorandum prepared for the USEPA. June.

Chen, Y., J.J. Bonzongo, and G.C. Miller. 1996. Levels of Methylmercury and Controlling Factors in Surface Sediments of the Carson River System, Nevada. *Environmental Pollution* 92:281-287

Chen, Y., J.J. Bonzongo, W.B. Lyons, and G.C. Miller. 1996. *Inhibition of Mercury Methylation by Group VI Anions*, Fourth International conference on Mercury as a Global Pollutant, Hamburg, Germany. (Abstract)

Ecology and Environment, Inc. (E&E). 1997, *Development of Remediation-Related Hypotheses and Questions, Carson River Mercury Site.*

Ecology and Environment, Inc. (E&E). 1998. *Ecological Risk Assessment Carson River Mercury Site Upstream of Lahontan Dam.* Prepared for US EPA, Reg IX. San Francisco.

Fenstermaker, L.K. 2002. Identification of Mill Tailings within the Carson River Watershed using High Spectral Resolution Data. Desert Research Institute, University and Community College System of Nevada. Cooperative Agreement #CR816826. Prepared for the Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. EPA. October.

Gandhi, N. and M. Diamond. 2003. Development of Mercury Speciation, Fate, and Bioaccumulation Model: Application to the Lahontan Reservoir, Nevada. Report submitted to CH2M HILL and USEPA from University of Toronto, Canada, March.

Gandhi, N. S.P. Bhavsar, M. Diamond, J.S. Kuwabara, M. Marvin-DiPasquale, and D.P. Krabbenhoft. 2007. Development of a Mercury Speciation, Fate, and Biotic Uptake (BIOTRANSPEC) Model: Application to Lahontan Reservoir, Nevada, USA. Env. Tox. and Chem. Vol. 26. In press.

Gustin, M.S. 2001. Mercury Emissions from Lake Lahontan: A 24 Hour Study. Prepared for US EPA, Reg IX, San Francisco.

Gustin, M.S., G.E. Taylor, Jr., and T.L. Leonard. 1994. High Levels of Mercury Contamination in Multiple Media of the Carson River Drainage Basin of Nevada: Implications for Risk Assessment, *Environmental Health Perspectives, Journal of the National Institute of Environmental Health Sciences,* Volume 102, Number 9, 772-778.

Hallock, R.J., H.L. Burge, and P.L. Tuttle. 1993. Biological pathways - Movement of selenium and mercury. Pages 39-53 *in* R.J. Hallock and L.L. Hallock (eds.), Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada, 1987-90, Part B-Effect on biota in Stillwater and Fernley Wildlife Management Areas and other nearby wetlands. U.S. Geological Survey Water-Resources Investigations Report 92-4024B.

Henny, C.J., D.J. Hoffman, J.O. Keith, M. Spalding, and E.F. Hill. 1998. *Progress Report: Effects of Mercury on Fish-Eating Birds Nesting Along the Carson River Drainage, Nevada.*

Henny, C.J., Hill, E.F., Grove, R.A., Kaiser, J.L., 2007, Mercury and drought along the lower Carson River, Nevada- I. Snowy egret and black-crowned night-heron annual exposure to mercury, 1997-2006: Archives of Environmental Contamination and Toxicology, v. 53, p. 269-280.

Henny, C.J., Hill, E.F., Hoffman, D.J., Spalding, M.G., Grove, R.A., 2002, Nineteenth century mercury- Hazard to wading birds and cormorants of the Carson River, Nevada: Ecotoxicology, v. 11, no. 4, p. 213-231.

Hoffman, R.J. 1994. *Detailed Study of Irrigation Drainage In and Near Wildlife Management Areas, West-Central Nevada, 1987-1990, Part C, Summary of Irrigation-Drainage Effects on Water Quality, Bottom Sediment, and Biota.* U.S. Geological Survey, Water-Resources Investigations Report 92-4024C, Carson City, NV.

Hoffman, R.J. and R.L. Taylor. 1998. Mercury and suspended sediment, Carson River Basin, Nevada – Loads to and from Lahontan Reservoir in the flood year 1997 and deposition in Reservoir prior to 1983. Carson City, NV, U.S. Geological Survey, Fact Sheet FS-001-98.

Hoffman, R.J., R.J. Hallock, T.G. Rowe, M.S. Lico, H.L. Burge, and S.P. Thompson. 1990. *Reconnaissance Investigations of Water Quality, Bottom Sediment, and Biota Associated with the Irrigation Drainage in and Near the Stillwater Wildlife Management Area, Churchill County, Nevada.* 1986-87 United States Geological Survey Water Resources Investigations Report 89-4105.

Kuwabara, J. S., M. M. DePasquale, W. Praskins, E. Byron, B. Topping, J. L. Carter, S. V. Fend, F. Parchaso, D. P. Krabbenhoft, and M. S. Gustin. 2002. Flux of Dissolved Forms of Mercury Across the Sediment-water Interface in Lahontan Reservoir, Nevada. U. S. Dept. Of Interior, USGS Water Resources Investigation Report. 02-4138.

Lechler, P.J., J.R. Miller, L. Hsu, and M.O. Desilets. 1995. Understanding Mercury Mobility at the Carson River Superfund Site, Western Nevada, United States: Interpretation of Mercury Speciation Results from Mill Tailings, Soils, and River and Reservoir Sediments, proceedings of the 10th International Conference on Heavy Metals in the Environment, Hamburg, Germany.

Lechler, P.J., J.R. Miller, Liang-Chi Hsu, and M.O. Desilets. 1995. *Understanding Mercury Mobility at the Carson City Superfund Site, western Nevada, USA: Interpretation of Mercury Speciation Results from Mill Tailings, Soils, and River and Reservoir Sediments.*

Mach, C. and S. Peterson. 1999. Analysis of Carson River Data Collected by USGS. Report by E&E Inc. to Wayne Praskins, EPA, 23 February 1999.

Marvin-DePasquale, M. 2003. Water column mercury speciation determinations. Unpub. Data. Prepared for US EPA, Reg. IX, San Francisco.

Marvin-DePasquale, M. and J. Agee. 2001. Methylmercury Formation and Degradation in Sediments of the Carson River System. Administrative Report, USGS, Menlo Park, CA. Prepared for US EPA, Reg. IX. San Francisco. December.

Miller, J.R., P.J. Lechler, and M. Desilets. 1998. The Role of Geomorphic Processes in the Transport and Fate of Mercury in the Carson River Basin, West-Central Nevada 249-262.

Miller, J.R., P.J. Lechler, J. Rowland, M. Desilets, and L. Hsu. 1995. An integrated approach to the determination of the quantity, distribution, and dispersal of mercury in Lahontan Reservoir, Nevada, USA. Journal of Geochemical Exploration 52:45-55

Miller, J.R., P.J. Lechler, J. Rowland, M. Desilets, and Liang-Chi Hsu. 1994. Dispersal of Mercury-Contaminated Sediments by Geomorphic Processes, Sixmile Canyon, Nevada, USA: Implications to Site Characterization and Remediation of Fluvial Environments.

Nevada Department of Environmental Protection (NDEP). 1985. Total Mercury in Sediment, Water, and Fishes in the Carson River Drainage, West-Central Nevada.

Nevada Department of Wildlife (NDOW). 2006. Nevada Mercury Study, Western Region. Unpublished Data on Mercury Concentrations from 10 Species of Fish Sampled from Lahontan Reservoir, NV in July and August, 2005.

Richins, R.T., and A.C. Risser, 1975, Total mercury in Water, sediment, and selected aquatic organisms, Carson River, Nevada. *Pesticide Monitoring Journal* 9:44-54.

Tuttle, P.L., C.A. Janik and S.N. Wiemeyer. 1996. Stillwater Wildlife Refuge wetland contaminant monitoring. U.S. Fish and Wildlife Service, Reno, NV. 67 pp.

Tuttle, P.L., D.K. Higgins, and J. Quashnick. 2001. Mercury Characterization in Lahontan Valley Wetlands, Carson River Mercury Site, Lyon and Churchill Counties, Nevada, 1999. USFWS, Div. of Env. Contaminants, Reno, NV.

U.S. Environmental Protection Agency (USEPA). 1996. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 3, Overview of Risk Management.*

U.S. Fish and Wildlife Service (USFWS). 1999. Statement of Work, Carson River Superfund Site: Exposure to Mercury in Lahontan Valley Wetlands.

U.S. Geological Survey (USGS). 1997. Field Sampling Plan, Effects of Mercury on Fish-Eating Birds Nesting along the Mid to Lower Carson River, Carson River Mercury Site, Lyon and Churchill Counties, Nevada.

USGS. 1998. Addendum to Field Sampling Plan, Carson River Mercury Site, Lyon and Churchill Counties, Nevada.

USGS. 1999a. Addendum to Field Sampling Plan, Effects of Mercury on Fish-Eating Birds Nesting Along the Mid to Lower Carson River, Carson River Mercury Site, Lyon and Churchill Counties, Nevada.

USGS. 1999b. Field Sampling Plan, Methylmercury Formation and Degradation in Sediments of the Carson River System, Carson River Mercury Site, Lyon and Churchill Counties, Nevada.

USGS. 1999c. Methylmercury Formation and Degradation in Sediments of the Carson River System.

Warwick, J. J. and K.J. Heim. 1995. Hydrodynamic Modeling of the Carson River and Lahontan Reservoir, Nevada, *Water Resources Bulletin, American Water Resources Association*, Volume 31, No. 1, 67-77.